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An Input-Process-Output Model of Pilot Core Competencies

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Abstract

The aim of this study was to investigate the relationship between the flight-related core competencies for professional airline pilots and to structuralise them as components in a team performance framework. To achieve this, the core competency scores from a total of 2,560 OPC (Operator Proficiency Check) missions were analysed. A Principal Component Analysis (PCA) of pilots' performance scores across the different competencies was conducted. Four principal components were extracted and a path analysis model was constructed on the basis of these factors. The path analysis utilising the core competencies extracted adopted an 'Input – Process – Output' (IPO) model of team performance related directly to the activities on the flight deck. The results of the PCA and the path analysis strongly supported the proposed IPO model.

Keywords: Pilot Competencies; Pilot Performance; Proficiency Check

Introduction

Flight safety is of utmost importance for any airline and a variety of safety mechanisms and procedures are in place to assure the safe operation of the aircraft. The roots of most aircraft accidents are manifold. They have complex interrelationships with all aspects of the operation of a modern airliner. Dekker (2001) observed that error on the flight deck was a product of equipment design, procedures, training and the environment. The UK Civil Aviation Authority (2013) review of fatal accidents indicated that 66% of all fatal accidents involved at least one airline-related causal factor. Flight crew handling/skill was the most commonly assigned causal factor, followed by various errors relating to omission or inappropriate crew actions. Crew Resource Management (CRM) and decision-making continued to account for over 20% of all causal factors. Of the top ten causal factors allocated for all fatal accidents between 2002- 2011, seven were related to human performance issues that fell within the remit of the airlines. It is therefore essential that the pilots' technical and non-technical flying skills meet the requirements of the industry's safety and quality standards. The aviation authorities require the airline pilots' proficiency to be routinely evaluated to verify their ability to carry out their flying duties safely. The airlines typically conduct various proficiency checks annually or semi-annually to meet this requirement and to verify that the aviation authorities' and operators' performance standards are satisfied. Modern, high fidelity simulators allow most proficiency check rides to be flown in a simulated environment (Huddlestone & Harris, in press; Mansikka *et al*., 2016; Sarter *et al*., 2007; Weitzman *et al*., 1979).

In the aviation industry, proficient performance is often described as a group of related competencies. Instructors and flight examiners assess the competencies of pilots against national or international standards for their continued accreditation and/or type-rating training

(Roth, 2015). The idea of formulating the required skills, knowledge and attitudes as competencies is not a new one; in 1973 McClelland suggested that when an operators' job performance is assessed, the operators should be tested for relevant competencies instead of testing them for a set of more general aptitudes such as IQ tests (McClelland, 1973). While multiple definitions exist for such competencies, they all refer to observable and measurable descriptions of knowledge, skills, abilities and personal attributes underpinning successful job performance (European Centre for the Development of Vocational Training, 2010). Competencies are defined by the requirements of the job not the characteristics of the job incumbent. However, the performance standards required in each of the competencies form the basis of a job description and ongoing assessment (Harris, 2011). The use of competencies in the aviation domain originates from the joint efforts of the United States Air Force Research Laboratory and the United States Air Force Major Command, Air Combat Command (Bennett Jr, *et al.*, 2002).

The competencies, or the desired set of skills, knowledge and attitudes, can be divided into core competencies (or mission essential competencies) and supporting competencies. In the commercial air transport domain, the core competencies are statements of human attributes required for safe, effective and efficient operations of the aircraft. In commercial aviation, the core competencies have been formulated using data, or evidence, collected from accidents, incidents, operations and training. As a result, the training programs utilising the core competencies are often referred to as Evidence Based Training (EBT) programs. EBT programs are based on the assumption that when a pilot masters the predefined core competencies, s/he is more likely to perform up to the standards even when confronted with unexpected and unforeseen events during live operations. In other words, the core competencies serve as countermeasures to error and are also considered to underpin the pilots' ability to recover quickly from unsafe events, i.e. their resilience. During an operator proficiency check (OPC), a pilot's knowledge, skills and attitudes are evaluated against these core competencies.

When EBT is used to train overall crew performance, no distinction is made between those skills which in the past have been deemed to be either 'technical' (flight-related skills) or 'non-technical' (social skills), such as CRM (e.g. NOTECHS – Non-Technical Skills – van Avermaete, 1998; Flin *et al*., 2002). However, up until relatively recently there was no agreed core set of competencies (O'Connor *et al*., 2008). The competencies discussed in this study refer to those core competencies approved and published by the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA) (ICAO, 2013; IATA, 2013).

ICAO recognizes eight core competencies, which are: Application of Procedures (APK), Communication (COM), Aircraft Flight Path Management, automation (FPA), Aircraft Flight Path Management, manual (FPM), Leadership and Teamwork (LTW), Problem Solving and Decision Making (PSD), Situation Awareness (SAW), and Workload Management (WLM). In addition to the ICAO core competencies, Knowledge (KNO) is sometimes viewed as an additional core competency (IATA, 2013). Table 1 summarizes the core competencies and their definitions.

INSERT TABLE 1 ABOUT HERE

When the core competencies were originally formulated, they were purposed to capture the relevant pilot knowledge, skills, abilities and personal attributes. However, the relationship between these different core competencies was not formalized by ICAO. The main objective of competency analysis is to derive a competency model for a particular job role (Arnold *et al*., 2016). Furthermore, while the components in any model should reflect discrete job competencies, it is unlikely that they will be completely independent. Effective performance in some competencies (e.g. communication – see table 1) will facilitate better performance in other areas (e.g. managing resources and teamworking). As a result, the core competencies cannot be viewed as isolated and disconnected activities.

The competencies described by IATA (2013) and ICAO (2013) are a combination of both individual and team-related skills as flying a commercial airliner is very much a team activity. At a basic level, the competencies relate to activities such as information seeking, decision making, communication and the flight path control of the aircraft. Similar factors can be found in 'Input – Process – Output' (IPO) models of team performance (Hackman, 1987; Kozlowski *et al*., 1999; McGrath, 1984; Steiner, 1972). McGrath's (1984) IPO model of team performance consisted of a 'Communication Component' at the Input stage, further divided into a 'Task Component' and an 'Interpersonal Component', where the former consisted of task oriented behaviours and the latter comprised of activities related to social relations and leadership; 'Action Process' (at the Process stage); and 'Impact' (at the Output stage). This IPO relationship implies a strong degree of inter-dependence between components. The McGrath model is of particular relevance to CRM on the flight deck as it relates directly to communication and small group performance. It posits that task performance is a direct consequence of the communication within the team and the subsequent actions that they take. Relationships on the flight deck, communication and teamworking, and coordination of action to achieve a goal are all fundamental components in many models of CRM (e.g. NOTECHS; van Avermaete, 1998).

The aim of this study was to investigate the relationship between the core flight-related competencies and to structuralise them as components within an IPO team performance framework. This should help CRM instructors to better develop their training material, as the relationship between core competencies are not independent concepts. Furthermore, it should be easier for the Type Rating Instructors (TRIs) to identify the root causes of pilots' performance deficiencies.

Method

Participants

To investigate the relationship between the core flight-related competencies, the OPC performance data from 1,280 pilots were retrieved. Pilots were drawn from all fleets (312 from Airbus A320 fleet; 238 Airbus A330; 73 Airbus A340; 102 Airbus A380; 481 pilots from the Boeing 777 fleet and 74 Boeing 787). Each participant held a valid Airline Transport Pilot Licence or Multi Crew Pilot Licence and they operated as an active duty airline pilots. All pilots were employed by the same major middle-Eastern airline.

Flying Mission and Performance Rating

Participants flew a normal EBT OPC, which consisted of two separate simulator missions. The missions did not follow a strict script, but evolved based on the pilot's reactions. For each pilot, the performance data were retrieved from both simulator missions.

The simulator sessions took place on consecutive days, although there was no requirement to have the same instructor for both checks, therefore it was possible that gradings were undertaken by a different TRI in each session.

During EBT OPC, the pilots were graded against each of the core competencies described in Table 1 by the TRIs. The maximum performance score for each competency was ‘5’ whereas the minimum performance score was ‘1’. The performance scores were based on TRI’s subjective assessments. Each mission was rated by one of 157 different TRIs employed by the airline.

Analysis and Results

The core competency scores from a total of 2,560 EBT OPC missions were retrieved for analysis. Data were analysed with IBM SPSS software (version 22) and IBM AMOS (version 24).

Reliability

Inter-rater reliability (IRR) was not evaluated directly (e.g. using a videoed EBT OPC mission) as such a study would not have provided evidence whether the TRIs would have rated different EBT OPC missions similarly. However, IRR was evaluated using historical data. To explore IRR, 10 randomly selected, EBT OPC missions recently evaluated were selected for each TRI. An average of the competency scores awarded was calculated for each instructor. The descriptive statistics of the TRIs’ scores are summarized in Table 2. In addition, Figure 1 illustrates the means of the overall scores given by each TRI. Finally, Figures 2 and 3 illustrate the competency scores' distributions across TRIs. As the variance between TRIs' ratings seemed to be very modest, and there was a very large number of evaluators, it was expected that IRR did not notably affect the main findings of this study.

INSERT TABLE 2 ABOUT HERE

INSERT FIGURES 1-3 ABOUT HERE

Competency Ratings

The descriptive statistics of the core competency scores are summarized in Table 3.

INSERT TABLE 3 ABOUT HERE

To elicit the underlying latent structures in the data set, a Principal Component Analysis (PCA) was conducted. The Kaiser-Meyer-Olkin measure of sampling adequacy was exceptionally good, i.e. 0.946. Bartlett's test of sphericity was also highly significant; Chi-square=13973.000; df=36; $p<0.0001$. The measures of sampling adequacy for each variable ranged from 0.938-0.955 which suggested that the data set was appropriate for the PCA (Cerny & Kaiser, 1977; Dziuban & Shirkey, 1974). Table 4 shows the results of the PCA. Four principal components were formed and subjected to Varimax rotation with Kaiser normalisation. Overall, the principal components accounted for just over 82% of the variance in the sample. The variances attributable to the individual components extracted can be found in Table 5.

INSERT TABLES 4 and 5 ABOUT HERE

The principal components elicited from the data suggested four coherent underlying structures in the competency framework. Initially, the components were simply labelled A-D. Following the initial extraction of the principal components a recursive path analysis based upon the theoretical IPO model described by McGrath (1984) containing the meta-variables formed from the principal components A-D was constructed. Table 6 summarizes how the principal components and core competencies were seen to be related to different process stages of the IPO model. The model is described in Figure 4.

INSERT TABLE 6 ABOUT HERE

INSERT FIGURE 4 ABOUT HERE

The IPO model of team performance on the flight deck (based on McGrath, 1984) consists of a ‘Communication Component’, further divided into Task Component (TC) and an

Interpersonal Component (IC), 'Action Process' (AP) and 'Impact'. TC consists of task oriented behaviours and IC comprises of activities related to maintaining social relations.

Overall, the chi-square value for model fit was significant (χ^2=107.772; df=20; p<0.001) suggesting a discrepancy between the hypothesised path model and the data. Furthermore, the χ^2/df ratio was at the upper bounds of acceptability (5.386) (Marsh & Hocevar, 1985). However, any tests associated with the χ^2 statistic tend to be very sensitive to sample size. Other fit indices suggested that the model was an extremely good fit to the data. The Normed Fit Index (NFI) was 0.992 and the Comparative Fit Index (CFI) was 0.994, both of which were exceptionally good. The Root Mean Square Error of Approximation (RMSEA) value was also extremely low (0.045) suggesting a close fit of the data to the hypothesised IPO model in relation to the degrees of freedom (Browne & Cudeck, 1992). Hu & Bentler (1999) stated that any good model should have a CFI in excess of 0.95 and a RMSEA value lower than 0.06. In addition, the NFI value exceeded the limits recommended by Byrne (1994) and Schumacker & Lomax (2004), i.e. 0.90 and 0.95, respectively. The model presented in Figure 4 comfortably meets these criteria.

Discussion

In the aviation industry, the core competencies are a common way of describing how to effectively perform a piloting job and what a proficient pilot performance looks like. In EBT, the pilot's proficiency is trained and then assessed across a range of these core competencies (IATA, 2013; ICAO, 2013). It is considered that the core competencies capture the task essential knowledge, skills, abilities and attributes and, once mastered, enable the pilot to cope even with the unexpected, unforeseen real-life events and incidents. In this study, it was hypothesized that by conceptualizing the relationship between the core competencies it would be easier for the TRIs to address the root causes of pilots' performance deficiencies and CRM instructors would be better equipped to explain the concept of core competencies to the pilot community.

At the first step a PCA was conducted using the core competencies to identify underlying structures in the data. Four principal components were extracted (see Table 4), and at the second stage a model was constructed and tested using the resulting meta-variables and the core competencies (see Figure 4). To make the path analysis results more meaningful in the EBT context, the principal components extracted derived from the initial set of core competencies extracted were used to formulate an 'Input – Process – Output' (IPO) model of team performance (Hackman, 1987; Kozlowski *et al*., 1999; McGrath, 1984; Steiner, 1972).

The PSD and SAW competencies were regarded as task-oriented behaviours and requirements underpinning effective, goal driven team performance (e.g. Endsley, 1995; Jones, 1997; Wickens, 2002; Wickens & Liu, 1988). The function of the WLM competence within the TC component was posited to be associated with balancing the resources demanded by the PSD and SAW competencies. WLM, PSD and SAW formed the task-related aspect (TC) of the Communication Component. COM and LTW were essential functions for WLM application. In addition, COM and LTW were considered to be vital when team member's individual SAW and PSD are transformed into shared situation awareness and group decision making. Thus, they were considered as the elements of IC (Endsley, 1999, 2000; Jentsch *et al*., 1997). IC was hypothesised to act as a control structure driven by TC, overseeing the coordination and execution of AP and the control of the aircraft ('Impact' – the output stage in the IPO model). AP was theorized to comprise of KNO and APK. KNO was considered to represent the past experiences and mental models of crew members (e.g.

Baddeley & Hitch, 2000; Endsley, 1988; Wilson & Rutherford, 1989). In addition, it was rationalized that KNO and APK were functionally linked; together they formed an action process where knowledge was transformed into crew's activities. Finally, FPM and FPA, as overt and measurable actions, were hypothesised to form an 'Impact', or the output stage in the IPO model. It was acknowledged that the IPO model of team performance does not progress linearly, but has interactions between inputs, processes and outputs. In addition, the team performance is often considered to consist of several IPO cycles that run sequentially and simultaneously (Colquitt *et al.*, 2002; De Dreu & Weingart, 2003; Dirks, 1999; Janz *et al.*, 1997; Marks *et al*., 2001; Taggar, 2002). The model presented in this paper relates only to one, generic model of team performance on the flight deck. However, the basic principles within it may underpin the many IPO cycles running concurrently and consecutively during flight operations. This assertion would need evaluating in a future study.

The IPO model elaborated in this study structures the core pilot competencies and describes their inter-dependecies within in a team performance framework on the flight deck, providing a sound, validated model.

Conclusions

This study was successful in providing insights to the relationship between the core competencies and positioning them into a team performance framework described within an IPO model. When the core competencies are structured as the IPO model and the underlying relationship between them is revealed, it may be easier for the TRIs to capture the root causes of the performance deficiencies. For example, deficiencies in output competencies may have their ultimate cause in communication competencies factors. This may enable better targeted remedial training. In addition, the results of this study should help CRM instructors to further develop their CRM training materials.

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Note

This is a revised version of a paper presented at the 32nd European Association for Aviation Psychology conference, September 26-30, 2016 in Cascais (Portugal), by the same authors.

Table 1. Summary of pilot competencies (IATA, 2013; ICAO, 2013)

Competency	Competency Description
APK	Identifies and applies procedures in accordance with published operating instructions and applicable regulations using the appropriate knowledge.
COM	Demonstrates effective oral, non-verbal and written communications in normal and non-normal situations.
FPA	Controls the aircraft flight path through automation, including appropriate use of flight management system(s) and guidance.
FPM	Controls the aircraft flight path through manual flight, including appropriate use of flight management system(s) and flight guidance systems.
LTW	Demonstrates effective leadership and team working.
PSD	Accurately identifies risks and resolves problems. Uses the appropriate decision-making processes.
SAW	Perceives and comprehends all of the relevant information available and anticipates what could happen that may affect the operation.
WLM	Manages available resources efficiently to prioritize and perform tasks in a timely manner under all circumstances.
KNO	Demonstrates the knowledge required for safe and efficient operations. Demonstrates ability to source the necessary information.

Table 2. Minimums, maximums, means and standard deviations (SD) of the competency scores given by TRIs (n=157). Ten missions were selected for each TRI.

	APK	COM	FPA	FPM	KNO	LTW	PSD	SAW	WLM
Minimum	2.00	2.00	3.00	2.00	2.00	3.00	2.00	2.00	2.00
Maximum	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Mean	3.50	3.61	3.62	3.59	3.53	3.61	3.53	3.56	3.56
SD	0.28	0.26	0.28	0.29	0.29	0.28	0.28	0.27	0.28

Table 3. Minimums, maximus, means and standard deviations (SD) of the participants' OPC scores across the core competencies (n=2,560).

	APK	COM	FPA	FPM	KNO	LTW	PSD	SAW	WLM
Minimum	2.00	2.00	2.00	2.00	2.00	2.00	1.00	2.00	2.00
Maximum	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Mean	3.48	3.61	3.61	3.57	3.52	3.59	3.49	3.52	3.54
SD	0.54	0.50	0.49	0.51	0.53	0.50	0.52	0.54	0.52

Table 4. Loadings and the principal components (post Varimax rotation using Kaiser normalisation) based on the PCA; for clarity, loadings less than 0.50 have been omitted.

Variable	Component			
	A	B	C	D
SAW	0.782			
PSD	0.760			
WLM	0.664			
FPM		0.844		
FPA		0.727		
APK			0.814	
KNO			0.684	
COM				0.842
LTW	0.524			0.605

Table 5. Variances of the principal components.

	Component			
	A	B	C	D
Sum of Squared Loadings	2.357	1.771	1.640	1.634
% of Variance	26.193	19.674	18.217	18.158

Table 6. Principal components (Task Component -TC; Interpersonal Component - IC; Action Process – AP; and Impact) and core competencies as process stages of the IPO model (see Table 1 for abbreviations relating to the original competencies assessed).

IPO Stage		Component			
		A	**B**	**C**	**D**
INPUT	**TC**	WLM, PSD, SAW			
	IC				COM, LTW
PROCESS	**AP**			APK, KNO	
OUTPUT	**Impact**		FPA, FPM		

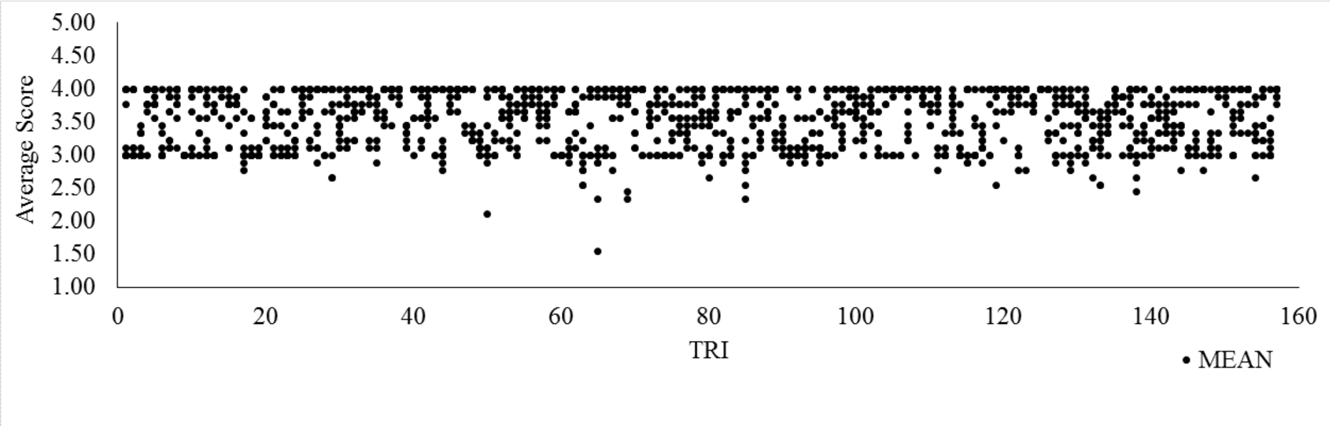

Figure 1. Means of TRIs' average overall scores (n=1,570).

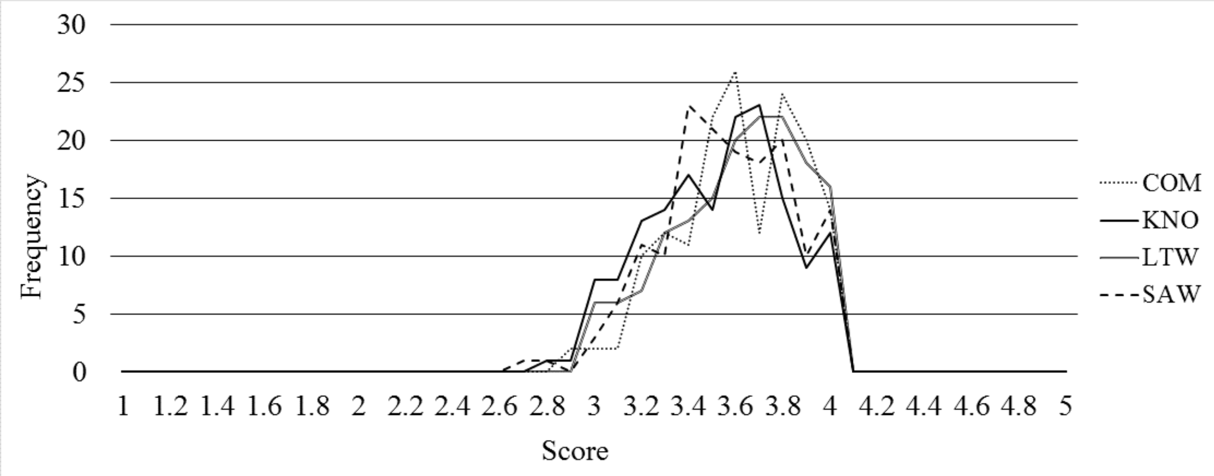

Figure 2. **Distributions of the average COM, KNO, LTW and SAW scores across TRIs (n=157).**

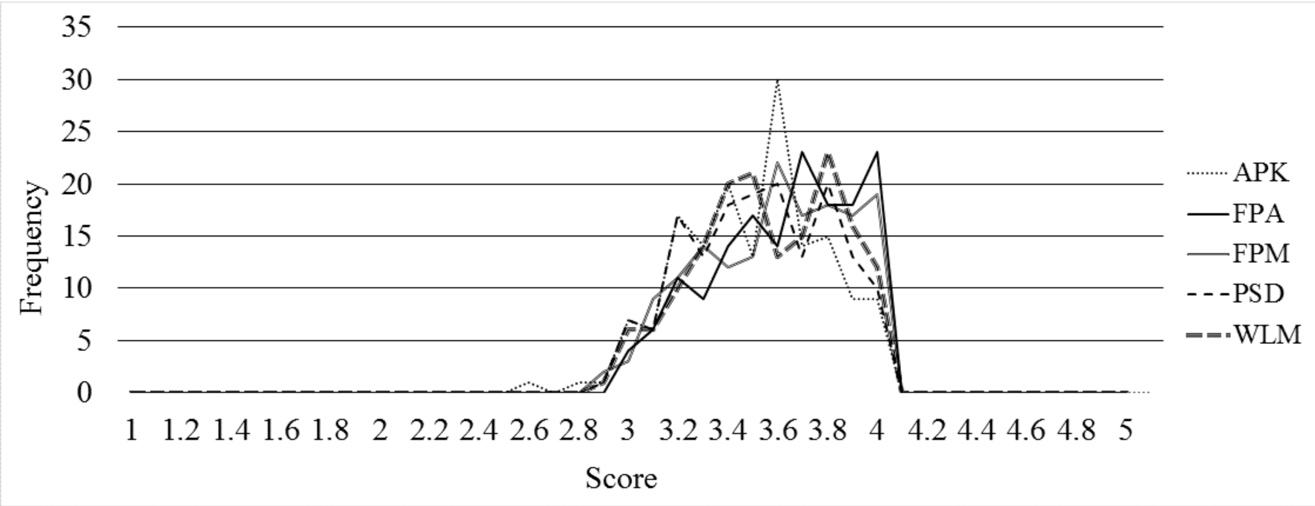

Figure 3. **Distributions of the average APK, FPA, FPM, PSD and WLM scores across TRIs (n=157).**

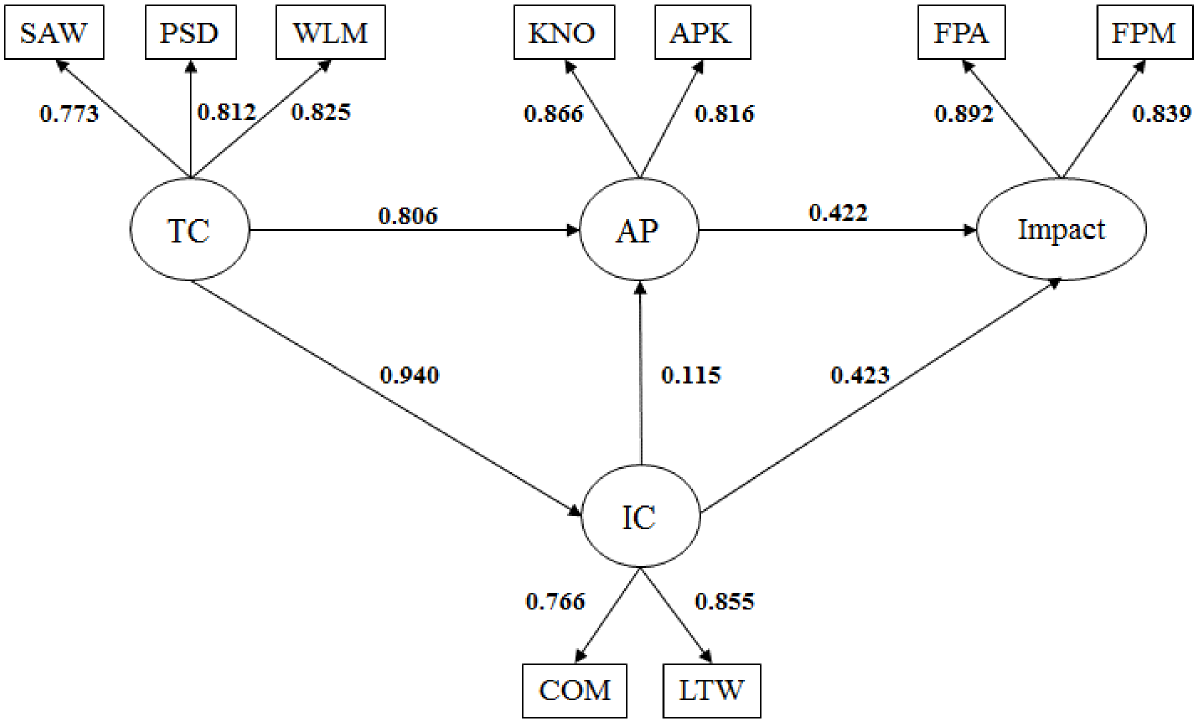

Figure 4. Path analysis model describing the IPO-model of team performance on the flight deck, based upon the meta-variables derived from the PCA described in Table 4. Weights are standardised regression weights (all were significant at p<0.0001). Note: for the clarity of presentation, the error terms have been omitted.